The High Resolution Spectrometer for SOFIA

Gerónimo Villanueva

Max Planck Institut für Aeronomie

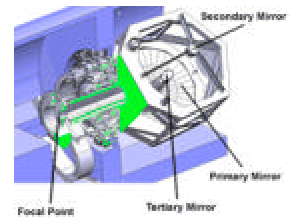
November 2002

Index

• SOFIA Observatory • Atmospheric transmission and sensitivity • GREAT-CTS Project	What?
• Scientific goals • Comets • Planetary atmospheres	Why?
• CTS Spectrometer function • Matching problematic – Chirp Generator • Numerical Simulations – Spurious contribution • Microstrip technologies	How?

- Estimated results – Profile retrieval
- Conclusions

SOFIA Observatory



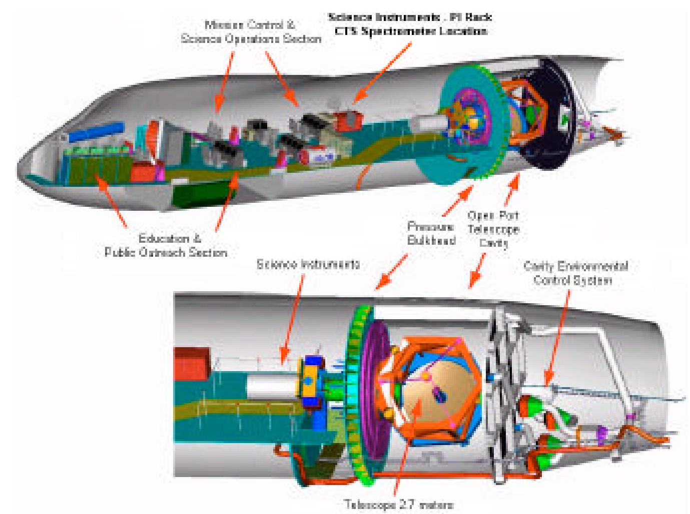
- Stratospheric observatory mounted onboard a Boeing 747-SP, that will fly at altitudes of 12.5 Km.

- Will avoid 99% of water vapor and 85% of the atmospheric absorption.

- The first flight is planned for 2004. The expected lifetime is of 20 years.

- A 2.7 meters Cassegrain type telescope will collect radiation from the complete IR range.

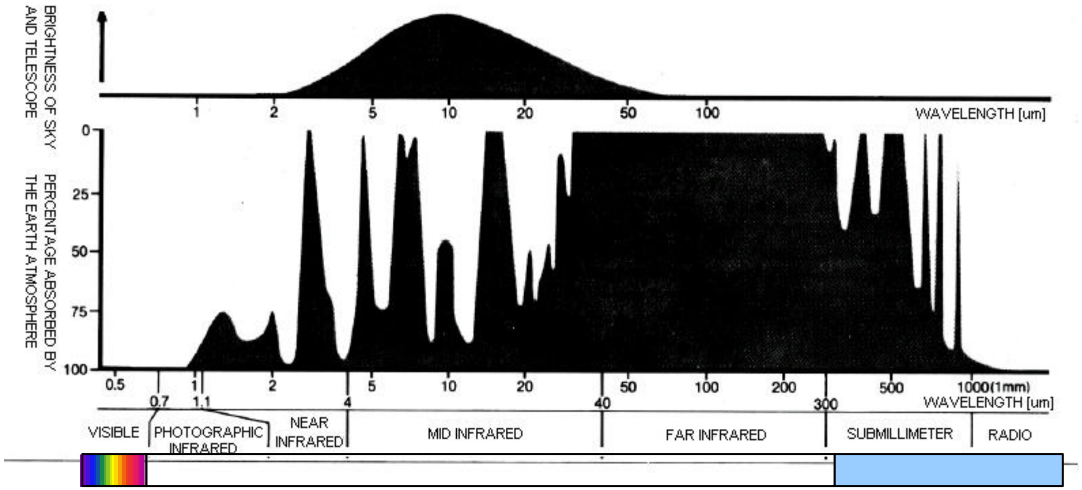
- Contains advantages of ground based observatories as high reusability and easy maintenance.

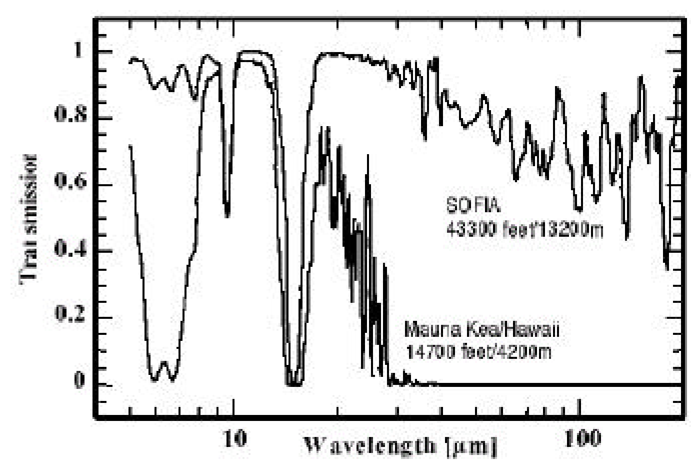


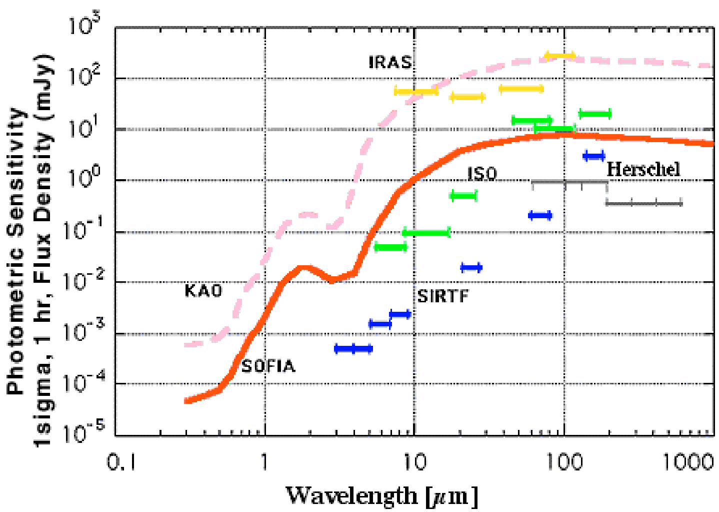
National Aeronautics and Space Agency

Deutschen Zentrum für Luft- und Raumfahrt

Atmospheric Transmission and Sensitivity





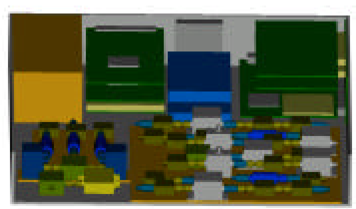


- Most of the infrared radiation is absorbed by our atmosphere.
- The sensitivity achieved by SOFIA is only improved in certain spectral ranges by space telescopes.

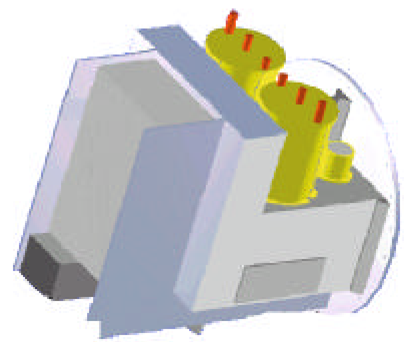
GREAT – German REceiver for Astronomy at Terahertz
CTS – Chirp Transform Spectrometer

- The incoming radiation is concentrated by a **primary** mirror, reflected to a **secondary** (Cassegrain disposition) and reflected finally to the instruments by a **tertiary** mirror.

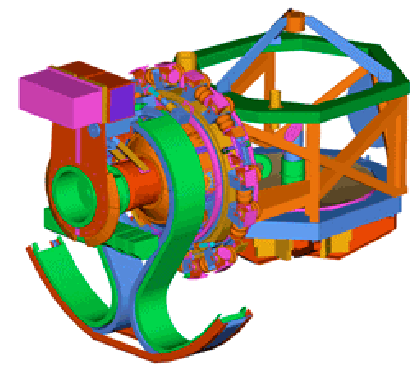
- The coherent detection performed in GREAT allows us to achieve much better sensitivity.



CTS provides high resolution spectroscopy of 50 KHz achieved by an analog-digital time-frequency transformation.



GREAT will receive the IR radiation through coherent detection, using a dual heterodyne process



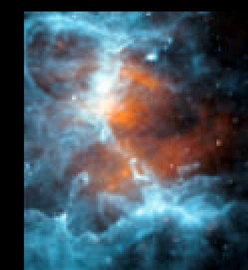
SOFIA Telescope will provide arc sec spatial resolution with a 2.7 meters main dish

Scientific goals

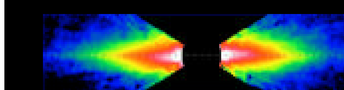
- **<u>Planets</u>:** the possibility to skip the strong absorption of the first 12 Km of the earth atmosphere, allow us to study in detail the composition of our neighbor planets.

- **<u>Comets:</u>** the volatile elements in the nucleus sublime under solar heating, providing spectral information of diverse chemical products and their kinematics.

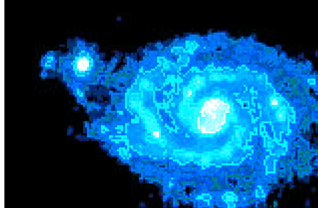
- **<u>Interstellar Medium:</u>** The ISM reflects the global history of a galaxy. Since most of the ISM is cold or, in the presence of a radiation field, warm, most of its continuum radiation and spectral line emission emerges in the MIR, FIR, and Submm.



- **<u>Star & Star Formation:</u>** Stars generally form through a fragmented collapse of a molecular cloud as a group or cluster.



- **<u>Evolution of Galaxies:</u>** With the advent of larger ground-based and space borne telescopes, covering a broad spectral range, galactic evolution has grown into a major research area.



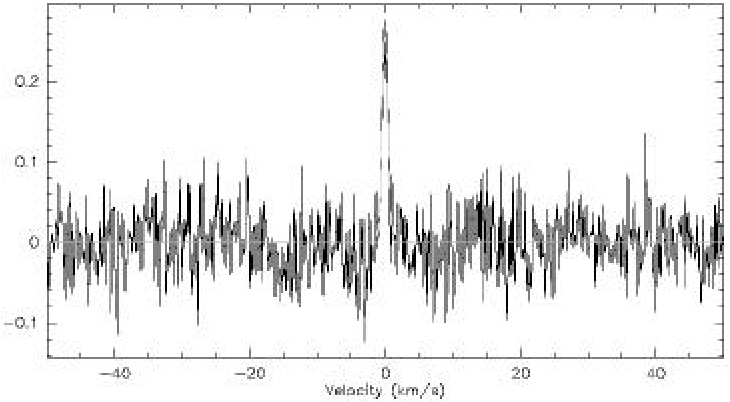
Comets

- The comet‘s nucleus temperature is in the range 150 K-240K (4AU-1AU) correspondant to a maximum according to Planck’s radiation law at 20 um and 10 um.

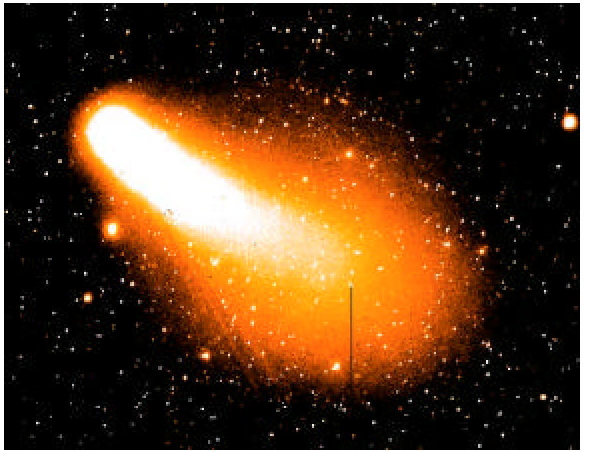
- With the high sensitivity provided by SOFIA and the high resolution by CTS we can obtain from the spectral line, molecular composition and kinematics information.

- A telescope at 12 Km will allow to obtain information of water vapor distribution, thanks to the possibility to avoid 99% of water vapor earth absorption.

Comet C/2000 WM1 (LINEAR)



HCN(4-3) rotational transition (845.68 µm) measured at Heinrich-Hertz Telescope, Arizona, USA with a Chirp Transform type spectrometer. December 6 2001.



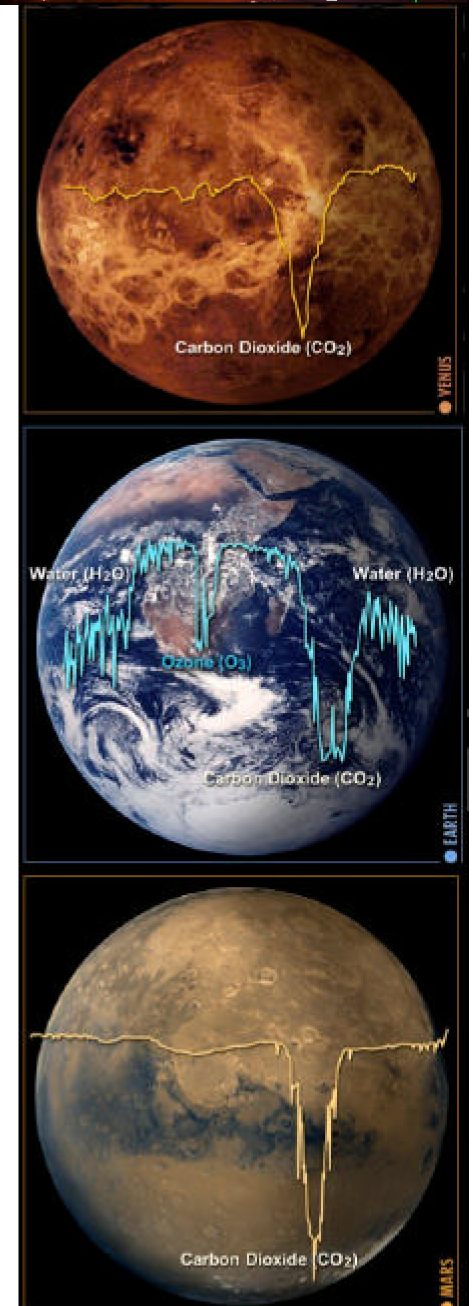
Comet image at the visual spectral range. December 6 2001.

Planetary atmospheres

- The opacity, the Doppler and pressure broadening of the molecular emissions provide us information about the three dimensional distribution of temperature, winds and composition.

- The retrieval of this information requires the knowledge of the exact line shape of the molecular emissions.

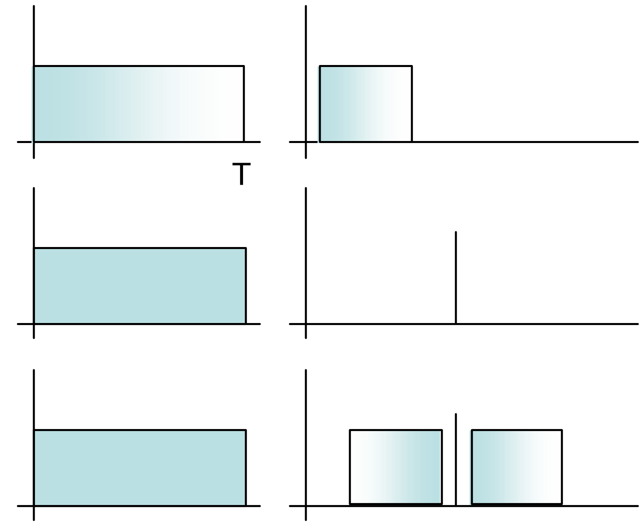
- Heterodyne spectroscopy can provide practically any arbitrary resolution. For SOFIA better than ?f/f=10^{-7}.



CTS Spectrometer function I

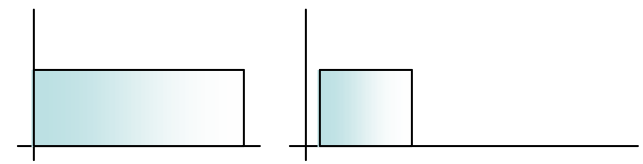
Time Frequency

- A chirp is a quadratic phase modulated signal with a length T e^{jpmt^2}
- The input signal, in this example shown as an harmonic $f(t)$
- We mixed, for example multiply both signals $f(t)\cdot e^{jpmt^2}$



The multiplied signal travels through a SAW (Surface Acoustic Wave) filter.

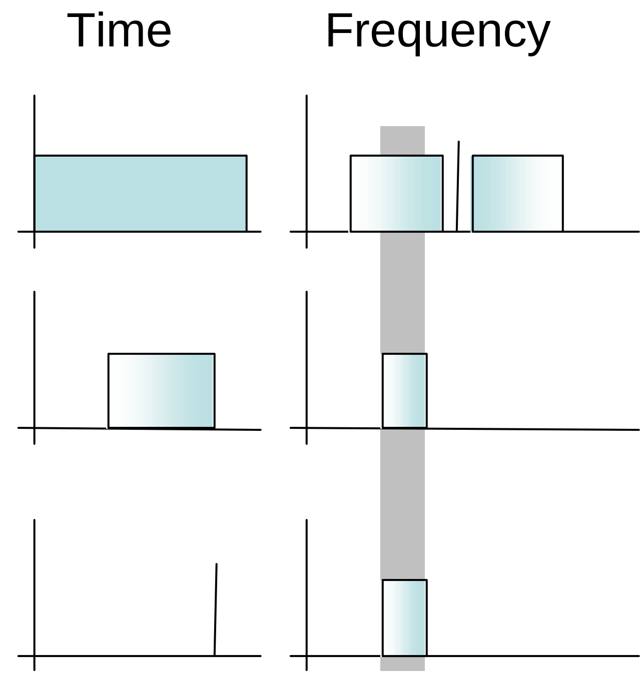
- The impulse response of a SAW filter is a chirp. e^{jpmt^2}



- This result is a time convolution

$$\int_{-\infty}^{+\infty}\left(f(t)e^{jpmt^2}\right)\cdot e^{j2pm(t-t)^2}dt$$

CTS Spectrometer function II



- This interaction represents a filtering of the signal
- And a time compression of the remaining chirp
- Adding a phase correction factor

$$e^{-jpmt^2}$$

$$e^{-jpmt^2}\int_{-\infty}^{+\infty}\left(f(t)e^{jpmt^2}\right)\cdot e^{j2pm(t-t)^2}\,dt$$

- And using the following substitutions

$$w = 2pmt \qquad 2tt = t^2 - t^2 - (t-t)^2$$

$$F(w) = \int_{-\infty}^{+\infty} f(t)e^{-jwt}\,dt$$

Matching Problematic – Chirp Generator

- The dispersive properties of the SAW filters depends on microscopic structures on the surface of a ceramic base

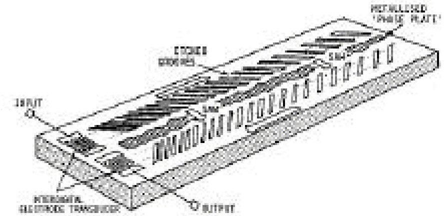


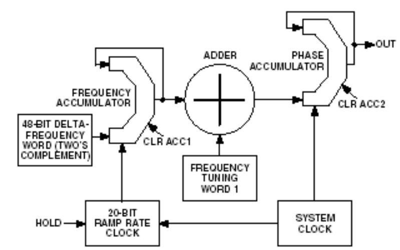
Fig 1, SAW-Filter

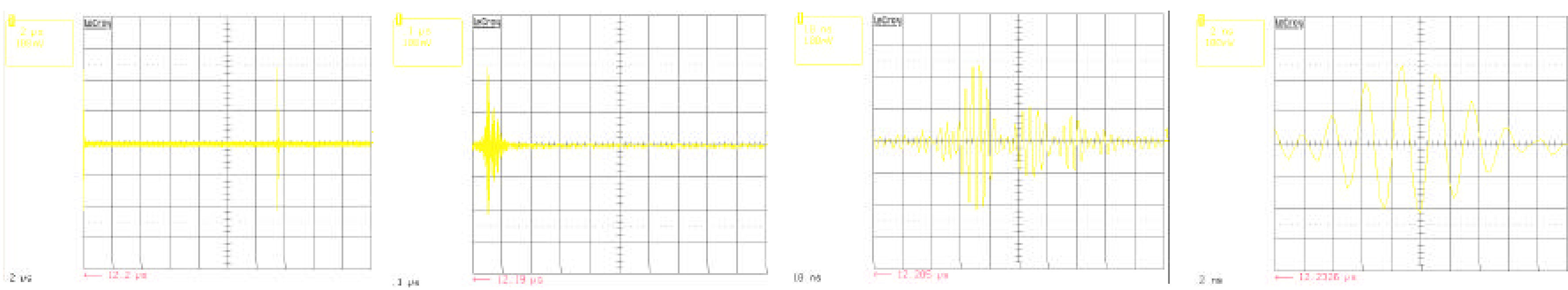
- Any microscopic variations or environment changes (T,p) will represent changes in these dispersion properties

$$e^{-jp(m+\Delta m)t^{2}}$$

- The matching of the expanded chirp signal and the compressor filter defines the resolution of the spectrometer

- It is used as an expander a DIGITAL chirp waveform generated by a quadrature phase digital synthesizer.





Numerical simulations – Spurious contribution

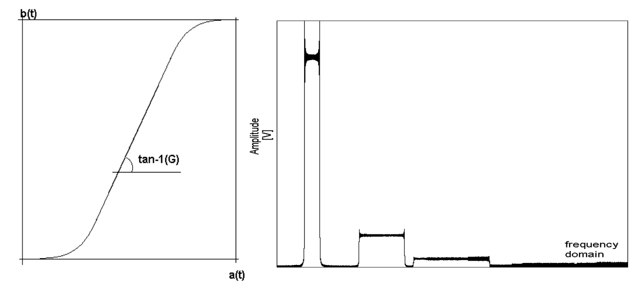
- There are two expander-compressor schema, the
- M(l)-C(s): expander bandwidth=2 *compressor bandwidth
- M(s)-C(l): expander bandwidth=½*compressor bandwidth

- It can be derived that the resolution depends inversely on the compressor bandwidth. So the most appropriate schema is the M(l)-C(s).

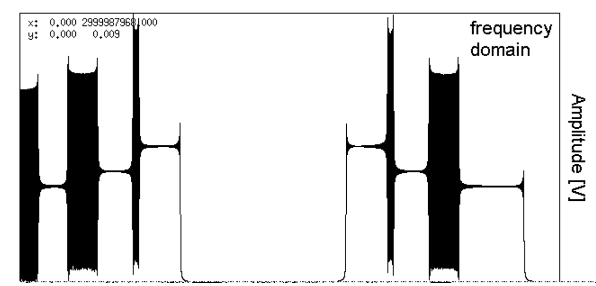
- This lead us to a big bandwidth of the expander achieved by frequency multiplication of the digital chirp waveform.

- Each device involved in the transformation is considered and the complete spectrometer is modeled.

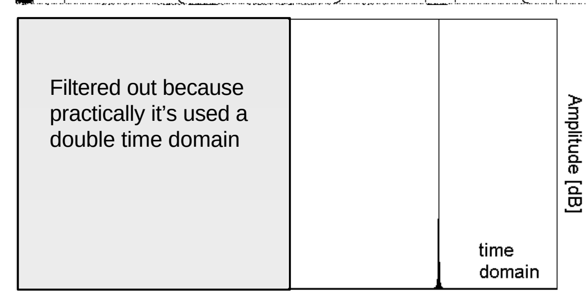
- From the results It is seen that the contribution of certain unwanted spurious doesn't affect the noise floor and the resolution.



Expanded



Compressed



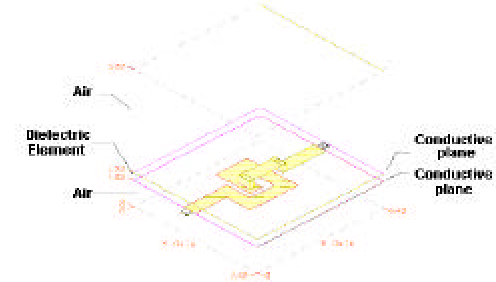
Microstrip technologies

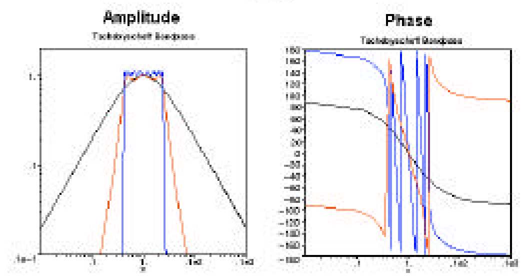
- The realization of frequency filters at GHz was possible thanks to studies of the electromagnetic field distribution over quasi-dielectric thin mediums (microstrip).

- It's used Tschebyscheff filter type (elliptical pole distribution) because its good frequency response.

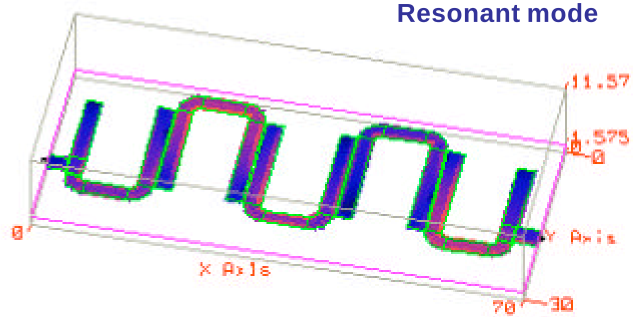
- Each complex pole is represented by a resonator element with a defined coupling.

- The strong limitation in space lead us to the development of compact, low-loss resonators based on miniaturized Hairpin resonators (Sagawa et al, 2002)

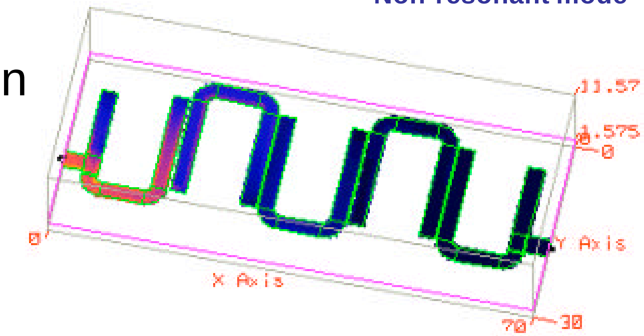




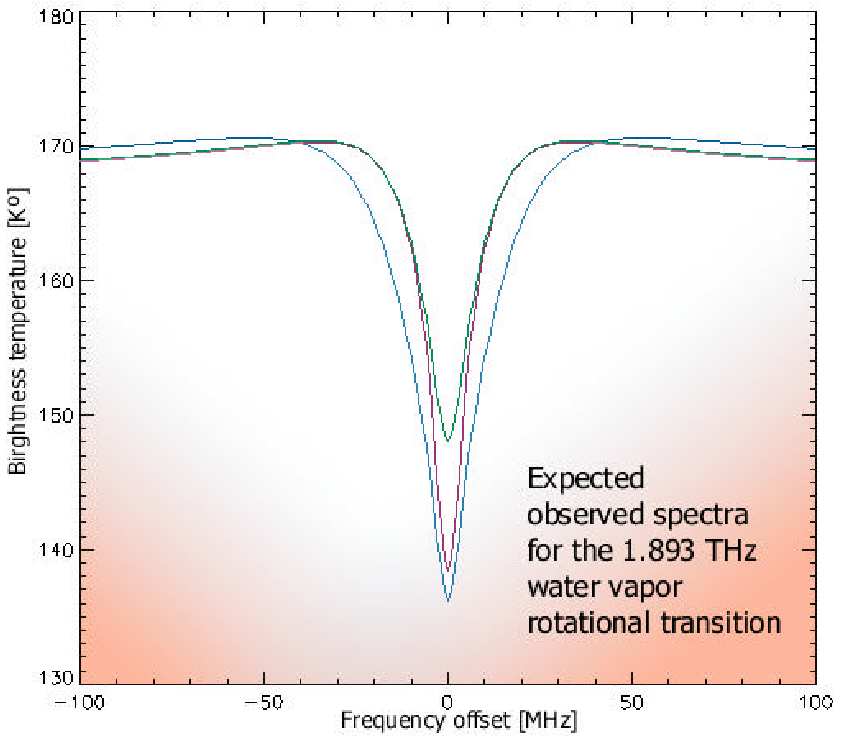
Resonant mode



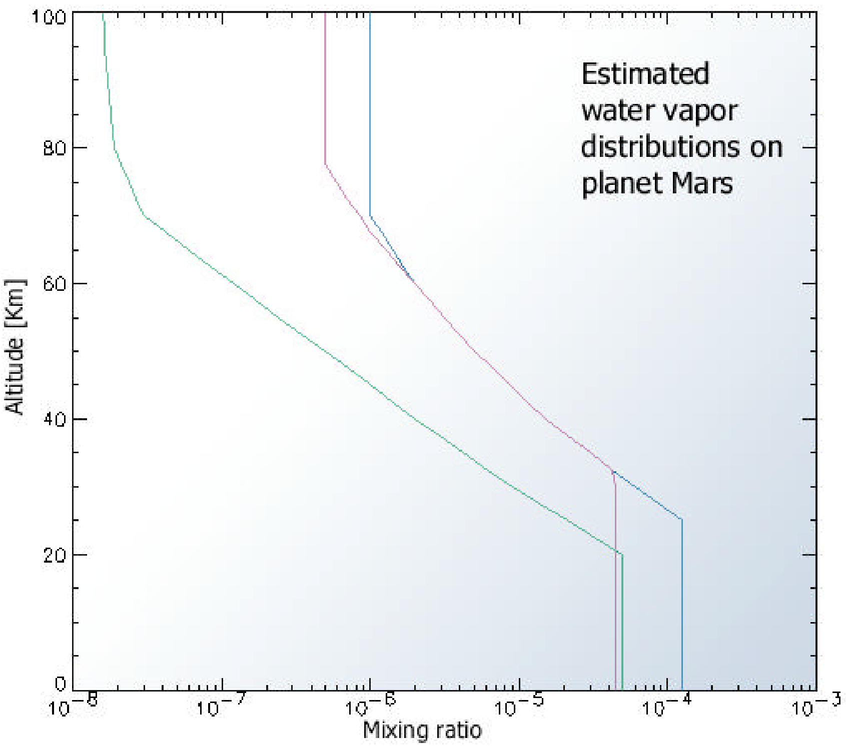
Non-resonant mode



Estimated results – Profile retrieval



Simulated spectral lines for the rotational transition of the water vapor molecule, considering the absorption for SOFIA at 13 Km.



Possible retrieved profiles of water vapor on the red planet. based on a modeled Martian atmosphere (Nair et al, 1994)

1.893 THz = 158.3 µm

Conclusions

- Scientific goals as comets, planetary atmospheres and the interstellar medium in the Galaxy to investigations related to the early Universe encouraged the development of SOFIA-GREAT-CTS.
- The joint between modeling, simulations and development of several technologies allow us to achieve the high scientific demands expected from the SOFIA observatory.
- High resolution spectroscopy in the infrared range represents big a challenge from the technological point of view, that until now was unreachable.

Future work

- Several simulations and laboratory measurements should be taken to obtain the optimum solution of the matching between the quadrature phase digital synthesizer and the SAW filter
- The generation of spurious in a controlled way, to do frequency multiplication need to contrasted by laboratory experiments for these high frequencies.
- A complete stabilization analysis should be done, to fit the scientific demands and to optimize the critical points.

SOFIA Related links & Introductory movie

- www.linmpi.mpg.de/projects/sofia
- www.sofia.nasa.gov
- spacesensors.dlr.de/sofia
- www.united-sofia.com

SOFIA Introductory movie